5. TESTING FOR NONLINEARITY IN G7 MACROECONOMIC TIME SERIES

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Abstract

In this study, we test the linearity of G7 macroeconomic time series over the period 1959Q1-1999Q4. The stationarity properties of this dataset was before tested by Aksoy and Ledesma (2008) employing unit root tests which are based on linear and nonlinear models. Aksoy and Ledesma (2008) concluded that the variables have uncertain order of integration. Therefore, by employing a recently introduced linearity test of Harvey et al. (2008), which is a powerful test even the order of integration is not certain, we test the linearity of this dataset to determine which kind of unit root test should have been used. We also show that more than half of the series are nonlinear which indicates the importance of testing the nonlinearity of macroeconomic time series.

Keywords: nonlinearity; time series; unit root; G7; stationarity

JEL Classification: C220

I. Introduction

Economy is nonlinear as stated by Granger and Terasvirta (1993). Even, "the real world is nonlinear" as expressed by Fan and Yao (2003, p.125). Testing and modeling this nonlinearity (especially threshold autoregressive (TAR) and smooth transition autoregressive (STAR) type) in economic and financial variables has become very popular over recent years[1] since traditional tests and models may lose power when the series under investigate are characterized by a nonlinear data generating process.

Not only several new linearity tests have been introduced in the last years, but also new unit root tests which consider nonlinearity in the data generation process have also been developed (see Kapetanios *et al*. 2003, Kapetanios and Shin, 2006, Sollis, 2009 and Kruse, 2010 among others). Based on the fact that these unit root tests have better power than the standard unit root tests (such as Augmented Dickey Fuller

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[1] *See Granger and Terasvirta (1993), Stock and Watson (1998), Franses and van Dijk (2000) and Clements* et al*. (2004) among others.*

unit root test), recent empirical studies employed the mentioned unit root test tests to test the stationarity of macroeconomic time series. For example, while Liew *et al*. (2004), Bahmani-Oskooee and Gelan (2006) and Zhou *et al*. (2008) investigated the purchasing power parity theory, Gustavsson and Österholm (2006, 2007), Craigwell *et al*. (2011) examined the unemployment hysteresis by using Kapetanios *et al*. (2003) unit root test. Chang (2012) approached to the Purchasing Power Parity hypothesis in a nonlinear framework by employing Kapetanios *et al*. (2003) and Sollis (2009) unit root test, Chortareas *et al*. (2003) investigated the current account solvency in Latin America countries, employing Kapetanios and Shin (2006) unit root test.

These studies test the unit root hypothesis against the nonlinear stationary processes. On the other hand, since there are some other studies which investigate same issues with linear unit root tests (see Bahmani-Oskooee, 1998 and Kalyoncu, 2009), and both linear and nonlinear unit root tests (see Aksoy and Ledesma, 2008) there emerges a question: Should we employ linear or nonlinear unit root tests? A solution to this problem is to use linearity tests and to pre-test the linearity of the series before determining the type of unit root test. However, linearity tests such as Teräsvirta (1994) and Luukkonen *et al*. (1988) are based on the assumption that the series are stationary, hence they lose power in the case of nonstationarity. Fortunately, recently Harvey et al. (2008) developed a new linearity test which is a powerful even the order of integration is not certain and also has good size and power property against both STAR and TAR alternatives.

In this study, we examine linearity properties of 43 quarterly time series of the G7 countries[2] over the period 1959-1999 which was categorized into four groups by Stock and Watson (2004) as “asset prices”, “activity”, “wages, goods and commodity prices” and “money” by employing Harvey *et al*. (2008) linearity test, to provide a guideline to the future studies which test the stationarity of the macroeconomic time series. The stationarity properties of this dataset was investigated before by Aksoy and Ledesma (2008) employing both linear and nonlinear unit root tests. They found 11.64 % of the series as stationary using linear unit root tests and 45.78% of the series as stationary by employing nonlinear unit root tests[3]. Thus, while some of the series found to be stationary employing linear unit root tests, they found to be as nonstationary using nonlinear unit root tests. Therefore, the linearity test of Harvey *et al*. (2008) can be used to determine the type of the unit root test (linear or nonlinear) which should has been employed to test the stationarity of the series.

We organized the remainder of the study as follows. Section 2 describes the linearity test. Section 3 presents the test results, and Section 4 summarizes and concludes the paper.

II. Econometric Methodology

The linearity test proposed by Harvey *et al*. (2008) referred to as the W_λ test, is applicable in cases in which the order of integration of the time series (y_t) under

[2] The G7 countries include the United States, Canada, the United Kingdom, Japan, Germany, France, and Italy.

[3] *See continuation of Table 3 on page 21 from Aksoy and Ledesma’s study for details.*

investigation is uncertain. This test statistic is calculated as follows:

$$W_{\lambda} = \{1-\lambda\} W_S + \lambda W_U \quad (1)$$

where: λ is a function that converges in probability to zero when y_t is $I(0)$ and to one when y_t is $I(1)$. The function can be computed by using

$$\lambda(U,S) = \exp\left(-g\left(\frac{U}{S}\right)^2\right) \quad (2)$$

in which, g is a finite positive constant[4]. U and S show unit root and stationarity test statistics, respectively. Harvey et al. (2008) suggest using the standard Dickey-Fuller unit root statistic for U and the nonparametric stationarity statistic of Harris et al (2003) for S. If y_t is $I(0)$, $(U/S)^2$ diverges, resulting in λ converging to zero, and if y_t is $I(1)$, $(U/S)^2$ converges to zero, resulting in λ converging to one.

Indeed, we have 3 linearity test statistics in (1); W_{λ}, W_S and W_U. W_{λ} is a weighted average of W_S and W_U which are test statistics used for testing linearity when the series is stationary or has a unit root, respectively. We now explain how these statistics are computed.

For an $I(0)$ time series y_t, t =1,…….T, where T is sample size, a nonlinear *AR(1)* model can be denoted as follows:

$$\begin{aligned} y_t &= \mu + v_t \\ v_t &= \rho v_{t-1} + \delta f(v_{t-1},\theta) v_{t-1} + \varepsilon_t \end{aligned} \quad (3)$$

where: ε_t is a zero mean *IID* white noise process. ρ, δ and the function $f(.,\theta)$ are chosen such that v_t is globally stationary. The function $f(.,\theta)$ is assumed to admit a Taylor series expansion at around $\theta = 0$, such that (3) is approximated to the second order by

$$v_t = \delta_1 v_{t-1} + \delta_2 v_{t-1}^2 + \delta_3 v_{t-1}^3 + \varepsilon_t \quad (4)$$

In (4), the null hypothesis of linearity and alternative of nonlinearity are expressed as

$$H_{0,S} : \delta_2 = \delta_3 = 0$$
$$H_{1,S} : \delta_2 \neq 0 \quad \text{and/or} \quad \delta_3 \neq 0$$

where: $H_{.,S}$ denotes a hypothesis under the assumption of y_t being *I(0)*. Equation (4) can be rewritten as a regression model in terms of the observed y_t:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 y_{t-1}^2 + \beta_3 y_{t-1}^3 + \varepsilon_t \quad (5)$$

In terms of Equation (5), the null and alternative hypotheses become

$$H_{0,S} : \beta_2 = \beta_3 = 0$$
$$H_{1,S} : \beta_2 \neq 0 \ \ and/or \ \ \beta_3 \neq 0$$

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[4] *Following Harvey* et al. *(2008) and Yoon (2009, 2010a, 2010b) we set g=0.1.*

The standard Wald statistic for testing of $H_{0,S}$ against $H_{1,S}$ is

$$W_S = T\left(\frac{RSS_S^r}{RSS_S^u} - 1\right)$$

where: RSS_S^u and RSS_S^r are, respectively, the residual sums of squares from the unrestricted OLS regression (Equation 5) and the restricted OLS regression under the null is:

$$y_t = \beta_0 + \beta_1 y_{t-1} + \varepsilon_t \quad (6)$$

W_S will follow an asymptotic $\chi^2(2)$ distribution under the null hypothesis.

W_U is a linearity test employed when the series under investigate is *I(1)* that is nonlinearity is assumed to enter through the first differences of y_t:

$$\begin{aligned} y_t &= \mu + v_t \\ \Delta v_t &= \phi \Delta v_{t-1} + \varsigma f(\Delta v_{t-1}, \theta)\Delta v_{t-1} + \varepsilon_t \end{aligned} \quad (7)$$

where: ρ , δ and the function $f(.,\theta)$ are chosen such that Δv_t is globally stationary. If the function $f(.,\theta)$ is assumed to admit a Taylor series expansion at around θ=0 again, (7) is approximated to the second order by

$$\Delta v_t = \varsigma_1 \Delta v_{t-1} + \varsigma_2 (\Delta v_{t-1})^2 + \varsigma_3 (\Delta v_{t-1})^3 + \varepsilon_t \quad (8)$$

The null of linearity and alternative of nonlinearity are given by

$$H_{0,U} : \varsigma_2 = \varsigma_3 = 0$$

$$H_{1,U} : \varsigma_2 \neq 0 \quad \text{and/or} \quad \varsigma_3 \neq 0$$

where: $H_{.,U}$ denotes a hypothesis under the assumption of y_t being *I*(I). (8) is rewritten as a regression model as follows

$$\Delta y_t = \varsigma_1 \Delta y_{t-1} + \varsigma_2 (\Delta y_{t-1})^2 + \varsigma_3 (\Delta y_{t-1})^3 + \varepsilon_t \quad (9)$$

Since $\Delta y_t = \Delta v_t$, (8) and (9) are essentially identical and the null and the alternative hypotheses are the same as given above. The corresponding Wald statistic

$$W_U = T\left(\frac{RSS_U^r}{RSS_U^u} - 1\right)$$

follows an asymptotic $\chi^2(2)$. Where RSS_U^u and RSS_U^r again denote, respectively, the residual sums of squares from the unrestricted OLS regression (Equation 9) and the restricted OLS regression under the null, i.e.

$$\Delta y_t = \varsigma_1 \Delta y_{t-1} + \varepsilon_t \quad (10)$$

Regression models (5, 6, 9, and 10) can be augmented to allow for higher order autoregressive models to account for serial correlation. We determine optimal lag length using general to specific method performed at the 5% level[5].

[5] *Yoon (2009) showed that Harvey* et al. *(2008) linearity test is not robust to outliers. Furthermore, in their paper, Chan and Ng (2004) showed that the five linearity tests which they examine in their study lose power in the existence of outliers. That is, the existence of outliers can affect the power of the linearity tests.*

III. Empirical Results

We tested the linearity of macroeconomic variables of G7 the countries over the period 1959Q1-1999Q4 by employing linearity test of Harvey *et al*. (2008). This dataset, which consists of up to 43 time series of the G7 countries, was previously used by Stock and Watson (2004) and Aksoy and Ledesma (2008) and is available at http://www.princeton.edu/~mwatson/publi.html. In their paper, Stock and Watson (2004) employed forecasts that based on individual predictors and also forecast combination methods to forecast output growth of the series. On the other hand, Aksoy and Leon-Ledesma (2008) tested the stationarity properties of the dataset by employing both linear and nonlinear unit root tests and obtained mixed results. Thus, by using the linearity test of Harvey et al. (2008) whose power is not effected by the integration of the series, we suggest which kind of unit root test should have been used for testing the stationarity of the series.

We presented the summary of the linearity test results as rejection percentages of the linearity hypothesis in Table 1[6]. We found 23 of 37 Canadian, 15 of 30 French, 24 of 35 German, 19 of 36 Italian, 14 of 37 Japanese, 21 of 32 UK and 34 of 43 US macroeconomic series as nonlinear. On the other hand, we found 75 of 125 of asset prices, 33 of 49 of activity, 21 of 34 of wages, goods and commodity prices and 21 of 38 of money time series as nonlinear. Consequentially, we found 60.40 % of the series as nonlinear. As compared to the other variables, the variables under the title of Activity, are found to be more nonlinear, the main reason of this nonlinearity is that these variables are more effected from the national and international events than the other variables (both national and international economic and political events may cause the nonlinearity of macroeconomic variables. For example, see the studies of Brooks and Hinich (1998) and Romera-Meza *et al*. (2007) which reveal the events that cause nonlinearity.

Table 1

Rejection Percentage of Linearity

	Canada	France	Germany	Italy	Japan	UK	US	Total
Asset Prices	61.11%	46.15%	68.75%	45.00%	43.75%	65.00%	81.82%	60.00%
Activity	50.00%	37.50%	87.50%	66.67%	62.50%	57.14%	75.00%	67.35%
Wages, goods and commodity prices	60.00%	80.00%	80.00%	50.00%	40.00%	80.00%	80.00%	61.76%
Money	83.33%	50.00%	33.33%	66.67%	0.00%	na	100.00%	55.26%
Total	62.16%	50.00%	68.57%	52.78%	37.84%	65.63%	81.40%	60.40%

Note: "na" indicates the unavailability of data series.

The nonlinearity in different variables is due to different reasons. The nonlinearity in the interest rates may be due to transaction costs (Zhou, 2011) and stock prices may be nonlinear because of the existence of heterogeneous agents (Killian and Taylor, 2003) and presence of market frictions. On the other hand, Reitz and Slopek (2009)

[6] *Appendix 1 shows the details. We replicate the data descriptions of the variables as defined by Stock and Watson (2004) in Appendix 2.*

asserted that the heterogeneous agents and their nonlinear trading impact cause the swings in oil prices. Term spread may be nonlinear, since risk premia may be time varying and exhibit nonlinearity as specified by Fama (1990).

The results that we obtained have two important implications. First, we found more than half of the series as nonlinear which shows that nonlinearity is an important property of macroeconomic series. Second; we suggest using Harvey *et al*. (2008) linearity test to determine the type of the unit root tests (whether linear or nonlinear) before testing the stationarity of the series, since using unit root tests which based on linear models can give inaccurate results if the data generation process is nonlinear.

IV. Conclusion

In this study, we employed a recently introduced linearity test of Harvey *et al*. (2008), which is powerful even if the order of integration is uncertain, and tested the linearity of G7 macroeconomic time series. This dataset has been before employed by Stock and Watson (2004) and Aksoy and Ledesma (2008). In their study, Aksoy and Ledesma (2008) tested the stationarity of the dataset by employing linear and nonlinear unit root tests. Since the results of these tests give mixed results, it can be stated that the integration properties of this dataset is uncertain. Thus, by employing Harvey et al. (2008) linearity test, we determine which kind of unit root tests should have been used in order to test the stationarity of the series. Furthermore, we suggest Harvey *et al*. (2008) linearity test to be employed before testing the stationarity properties of the series to determine whether linear or nonlinear unit root test should be used in future studies. On the other hand, the nonlinearity of more than half of the macroeconomic variables of G7 macroeconomic time series can be interpreted as the importance of testing nonlinearity in empirical studies.

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Appendix 1

Linearity Test Results

W_λ	Canada	France	Germany	Italy	Japan	UK	US
Asset Prices							
Rovnght	3.64	na	4.02	0.65	47.12*	1.04	11.76*
Rtbill	1.5	7.29**	2.35	8.53**	na	1.39	13.05*
Rbnds	Na	Na	na	11.33*	na	0.86	35.44*
Rbndm	Na	Na	na	4.15	na	na	31.95*
Rbndl	14.44*	2.65	6.16**	3.62	20.82*	19.4*	23.94*
Rrovnght	10.73*	Na	8.35**	9.65*	3.58	17.96*	5.39***
Rrtbill	0.57	2.51	12.28*	0.74	na	13.24*	15.41*
Rrbnds	Na	Na	na	1.35	na	12.45*	13.04*
Rrbndm	Na	Na	na	2.57	na	na	6.07**
Rrbndl	2.31	2.35	6.67**	4.19	6.05**	9.51*	3.38
Rspread	4.94***	Na	6.24**	9.88*	1.64	2.1	29.22*
Exrate	3.73	4.59	3.14	1.84	1.32	2.45	6.91**
Rexrate	1.55	8.71**	5.8***	3.17	0.77	11.14*	6.91**
Stockp	6.94**	5.28***	35.52*	5.88***	4	6.28**	21.13*
Rstockp	7.65**	3.77	19.58*	25.58*	4.22	4.85***	19.34*
Divpr	12.29*	10.06*	2.75	8.78**	22.21*	25.57*	8.91**
House	27.27*	Na	na	na	5.04***	4.9***	4.45
Rhouse	19.65*	Na	na	na	2.55	4.7***	0.15
Gold	2.56	4.86	9.66*	3.76	1.23	2.72	1.38
Rgold	6.23**	3.53	4.3	0.8	1.27	3.14	5.19***
Silver	53.53*	31.03*	33.14*	24.85*	44.97*	32.24*	49.24*
Rsilver	48.18*	22.01*	25.25*	25.84*	31.52*	19.61*	32.47*
Activity							
Rgdp	2.46	3.78	13.81*	8.32**	7.2**	17.23*	2.93
Ip	8.38**	7.7**	5.32***	14.03*	4.64***	8.73**	5.21***
Capu	1.77	0.44	21.36*	0.09	17.29*	na	7.07**
Emp	4.48	4.1	36.72*	na	4.26	0.6	8.85**
Unemp	5.75***	5.48***	18.34*	1	2.01	0.91	1.76
Pgdp	3.95	5.3***	0.21	10.55*	7.84**	3.94	4.67***
CPI	17.83*	1.52	12.6*	7.83**	3.75	13.07*	9.23*
PPI	22.19*	2.09	11.98*	na	5.36***	6.26**	7.43**
Wages, goods and commodity prices							
Earn	6.38**	5.49***	5.12***	na	9.44*	15.4*	3.07
Commod	25.68*	4.95***	3.47	8.9**	1.78	11.09*	35.55*
Oil	4.34	12.46*	12.51*	10.06*	3.67	9.56*	5.57***
Roil	3.36	5.48***	7.71**	4.06	6.83**	4.75**	2.99
Rcommod	5.25***	1.13	6.38**	2.01	3.4	0.63	0.55
Money							
M0	na	Na	na	na	3.59	na	105.1*
M1	5.45***	7.79**	1.06	28.1*	2.99	na	13.32*

W_λ	Canada	France	Germany	Italy	Japan	UK	US
M2	11.97*	Na	4.58***	9.12**	2.48	na	6.35**
M3	4.87***	5.11***	1.45	37.07*	2.71	na	6.76**
Rm0	na	Na	na	na	4.28	na	11.62*
Rm1	6.53**	0.03	0.23	3.76	3.19	na	6.19**
Rm2	7.06**	Na	0.66	4.65***	3.47	na	20.55*
Rm3	2.12	0.7	6.13**	4.38	3.97	na	13.94*

*Note: *, **, *** show rejection of the null hypothesis of linearity at 1%, 5%, 10 % levels respectively. “na” indicates the unavailability of data series.*

Appendix 2

Descriptions of Variables

Abbreviation	Description
CPI	Consumer Price Index
Capu	Index of Capacity Utilization
Commod	Commodity Price Index
Divpr	Dividend Price Index
Earn	Wages
Emp	Employment
Exrate	Nominal Exchange Rate
Gold	Gold Prices
House	House Price Index
Ip	Index of industrial Production
M0	Money: M0
M1	Money: M1
M2	Money: M2
M3	Money: M3
Oil	Oil Prices
Pgdp	GDP deflator
Ppi	Producer Price Index
Rbndl	Interest Rate: long term Government bonds
Rbndm	Interest Rate: Medium term Government bonds
Rbnds	Interest Rate: Short term Government bonds
Rcommod	Real Commodity Price Index
Rexrate	Real Exchange Rate
Rgdp	Real GDP
Rgold	Real gold prices
Rhouse	Real House Price Index
Rm0	Real Money: M0
Rm1	Real Money: M1
Rm2	Real Money: M2
Rm3	Real Money: M3
Roil	Real Oil Prices
Rovnght	Interest rate: overnight
Rrbndl	Real Long Term Bond Rate: rbndl-CPI Inflation
Rrbndm	Real Medium Term Bond Rate: rbndm-CPI Inflation
Rrbnds	Real Short Term Bond Rate: rbnds-CPI Inflation
Rrovnght	Real overnight rate: rovnght- CPI Inflation
Rrtbill	Interest rate: short term Government Bills
Rsilver	Real Silver Prices
Rspread	Term spread: rbndl-rovnght
Rstockp	Real stock price index
Rtbill	Real short term bill rate: rtbill- CPI Inflation
Silver	Silver Prices
Stockp	Stock price index
Unemp	Unemployment Rate